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DEFORMATION OF EXTRUDED TITANIUM ALLOYS UNDER SUPERPLASTIC CONDITIONS

by

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SUMMARY

The m-values, microstructure and deformation behaviour of an extruded U-channel section in IMI 550 and IMI 318 has been studied under conditions that produce superplasticity in these alloys in thin sheet form. The results are compared with those obtained for bar and sheet. Great Britain. (JES)

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Introduction

The potential cost and weight savings associated with superplastic forming of thin Ti-6Al-4V sheet structures [1] has led to increased interest in the forming of other product forms such as bar and extruded sections. However, compared with thin sheet, extruded Ti-6Al-4V alloy has a coarser and less uniform microstructure which would tend to be less superplastic than sheet. However enhanced superplasticity (100-300%) has been reported for β-Ti alloys having a large initial grain size [2-4] and this was attributed to dynamic recrystallisation in the β-phase during deformation [5]. In Ti-6Al-4V bar an aligned α+β phase microstructure at the test temperature was converted to an equiaxed microstructure during superplastic deformation although the initial microstructure caused flow stress and strain anisotopy [6]. In order to compare the behaviour of extruded material, a Ti-alloy extruded section was tested under superplastic conditions. The results of these tests are described in this paper.

Experimental Details

Alloy bars 220mm diameter with the compositions (wt%) of Ti-6Al-4V (IMI 318) and Ti-4Al-4Mo-2Sn-0.5Si (IMI 550) were extruded at 950°C into a U-channel section as shown in Fig 1. The extrusion was 176mm wide with a flange wall 37mm high x 27mm wide and a central web 122mm wide x 18mm thick. Round-bar test pieces aligned parallel to the principal directions L, T and ST were extracted from the flange and web as shown in Fig 1; gauge length dimensions were 15mm x 5.5mm diameter for the F_{ST} test piece and 20mm x 9mm diameter for the remaining test pieces.

Tests were carried out in argon at a true strain rate of $2 \times 10^{-4}\ s^{-1}$ at 925°C for IMI 318 and at 875°C for IMI 550 (similar to the conditions used for thin sheet [7-8]) to normal elongations up to 400%. The strain rate sensitivity index $m = d \ln \sigma / d \ln \dot{\varepsilon}$ was determined from cross-head speed changes in the range 4-25% elongation. The cross-sectional area after testing was determined from $A = \Pi ab$ where a, b were the maximum and minimum diameters in the gauge length and the area strain $\bar{\varepsilon} = \ln A/Ao$ where Ao = the inital cross-sectional area in the gauge length.

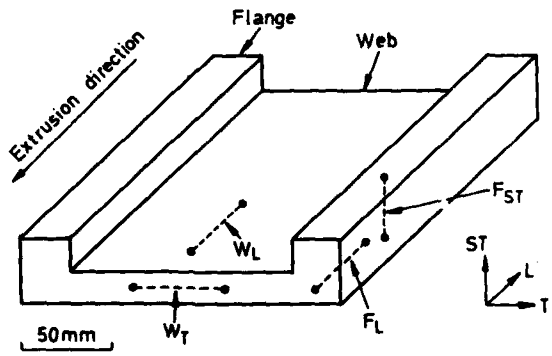

Fig 1 Position of test pieces in extruded section

Fig 2 Macrostructure of extruded IMI 318 near flange

Results

The macrostructure of the IMI 318 extruded section is shown in Fig 2. After thermally cycling (2h at 925°C, cooled 25°C/minute) the region at A in the web (Fig 2) had a microstructure with an aligned contiguous α-phase in the L and T directions as shown in Fig 3a for the ST-T plane. The corner region between the web and the flange (at B in Fig 2) was more equiaxed and the α-phase was not contiguous (Fig 3b). Test pieces cut from these two positions showed different deformation behaviour. For example at position A the W_L test piece (Fig 1) developed an eliptical cross-section in the gauge length after a strain of 1.36 as shown in Fig 3c; the maximum diameter was parallel to the T direction indicating a greater resistance to deformation in this direction compared with the ST direction. The cross-section of the test piece in position B (F_L in Fig 1) remained almost circular during deformation, as shown after a strain of 1.25 (Fig 3d). The ratio minimum diameter/maximum diameter indicated the degree of anisotropy and this ratio is plotted for all the test pieces versus area strain in Fig 4. With increasing strain all the test pieces except the F_L test piece exhibited increasing anisotropy. The maximum resistance to deformation was always in the direction of the contiguous α-phase. Similar results were obtained for the extruded IMI 550 alloy tested at the lower temperature of 875°C. The IMI 550 grain size was above half that for the Ti-6Al-4V extrusion before and after deformation.

With increasing strain the contiguity of the α-phase was destroyed and the microstructure became more equiaxed. This is shown in Fig 5 for extruded IMI 550; the aligned microstructure apparent after a thermal cycle (2h at 875°C, cooled 25°C/min) was replaced by a non-aligned microstructure after superplastic deformation to a strain of 1.67.

The m-values for the extruded alloys are plotted versus strain rate in Fig 6 and compared with the sheet data reported for these alloys [7-8]. The peak in the m v strain rate curves occurred at lower strain rates in the extruded materials than in the sheet and the m-values were greater and more sensitive to strain rate in the IMI 318 alloy than in the IMI 550 alloy at their respective test temperatures which was 50°C lower for the IMI 550 alloy. Elongations in the gauge lengths of up to 400% were non-uniform in all the extruded alloy test pieces. The initial flow stresses at strain rates of $\sim 10^{-4}$ s^{-1} were 21 MPa and 11 MPa for the IMI 550 and IMI 318 extruded material respectively compared with the corresponding values for sheet of 11.5 and 6 MPa.

Discussion

The results show that test conditions which caused superplastic deformation in thin IMI 318 and IMI 550 sheet did not produce uniform superplastic deformation when these alloys were in the form of an extruded section. The plastic anisotropy observed in the extruded materials was similar to that reported for rolled rectangular bar deformed under superplastic conditions and this was explained in terms of the resistance to grain boundary sliding in the α/α boundaries between the α-phase grains and the lower resistance to sliding in β/β boundaries between the β-phase grains at the test temperature [9]. In the present tests and in the tests reported on bar material plastic deformation converted the contiguous α-phase microstructure to a more uniform equiaxed microstructure.

It was also shown for the bar that further testing of superplastically deformed and re-machined test pieces caused this more uniform equiaxed microstructure to deform isotropically [10]. These changes in microstructure during plastic deformation have been correlated with texture changes in the bar [6] and in the extruded material [11].

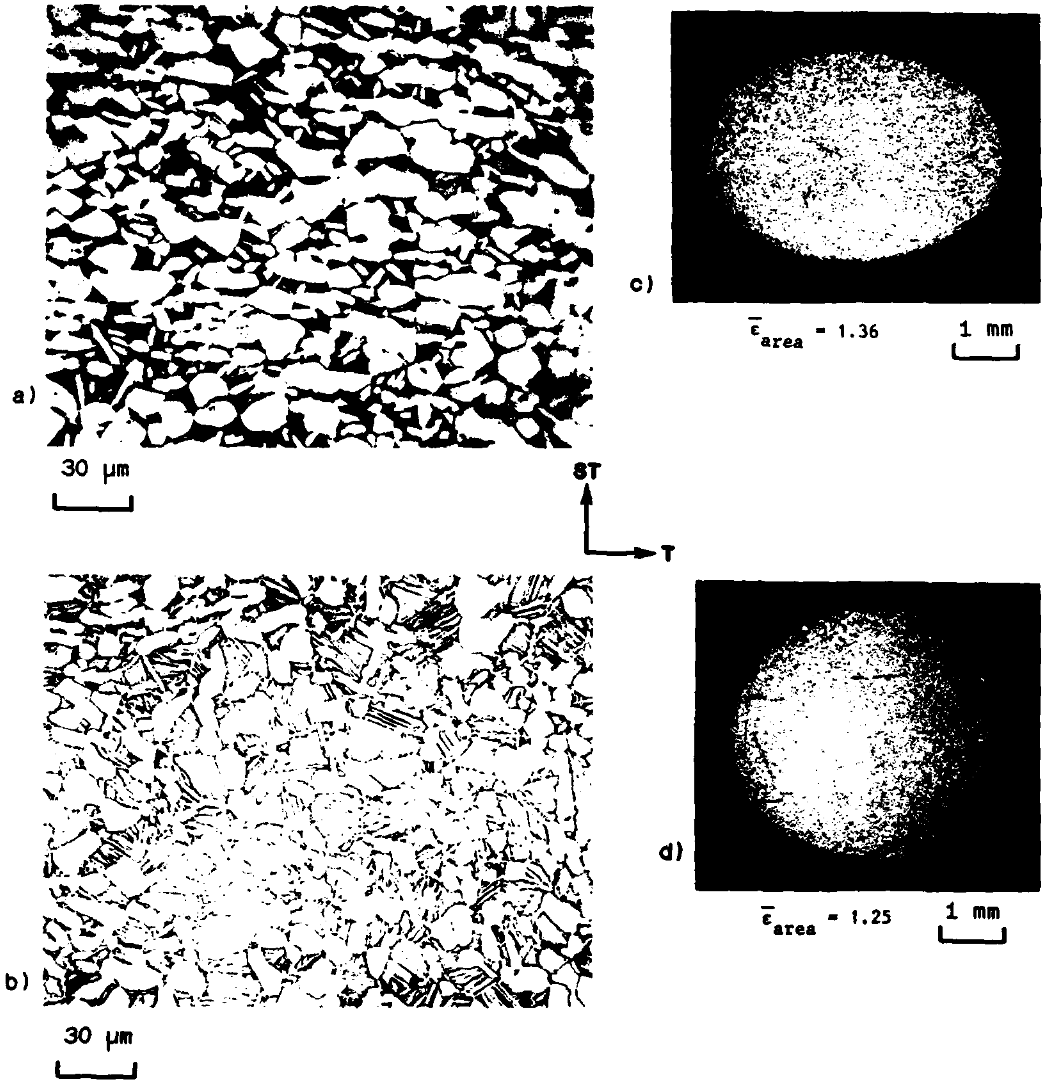

Fig 3 Microstructure of IMI 318 in (a) web section and (b) flange section after thermal cycle (2h at 925°C, cooled 25°C/min. Cross-section after deformation in (c) web section (W_L) and (d) flange section (F_L)

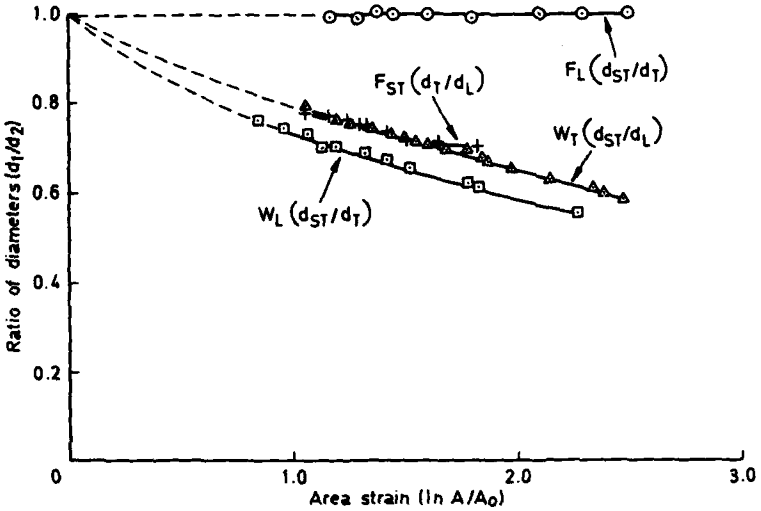

Fig 4 Ratio of minimum diameter/maximum diameter v area shown for IMI 318 test pieces

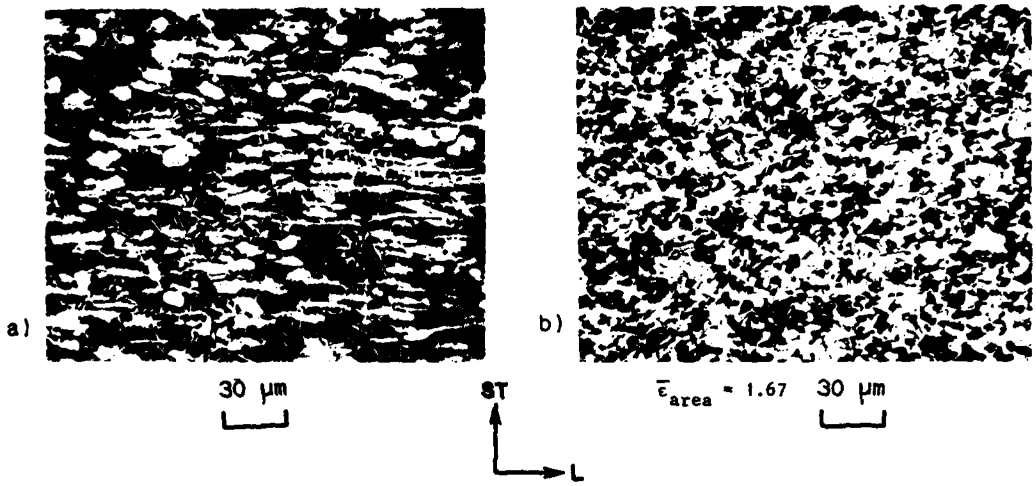

Fig 5 Extruded IMI 550 microstructures (a) after thermal cycle (2 hours at 925°C, cooled 25°C/min) and (b) after deformation (W_T).

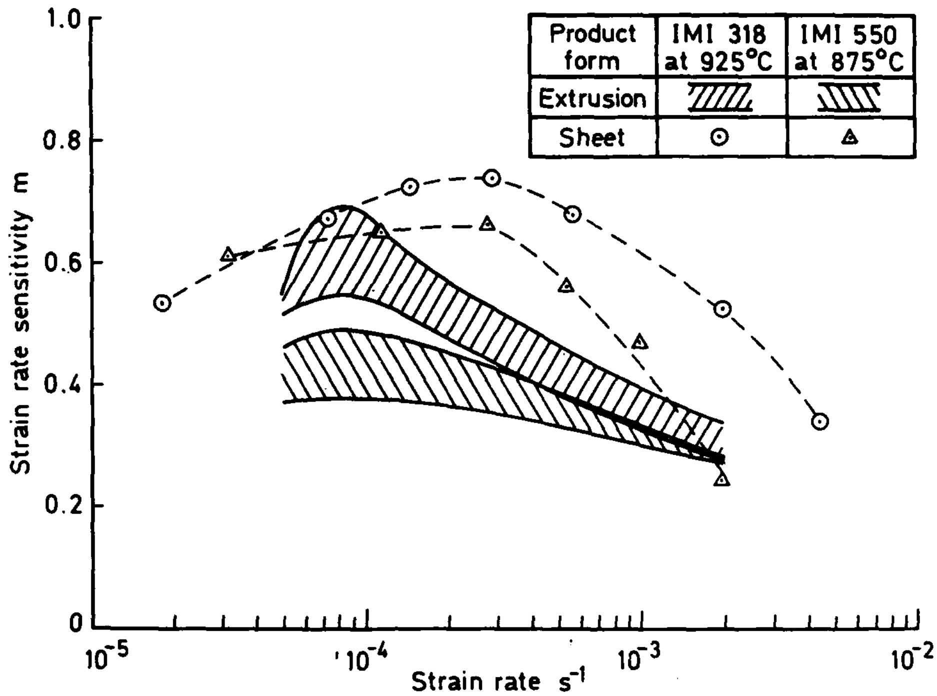

Fig 6 m-values v strain rate for IMI 318 and IMI 550 extrusions and sheet

The flow stresses in the extruded alloys were greater by a factor 2 than those reported for sheet material and in both product forms the flow stresses were a factor 1.5-2 greater in the IMI 550 alloy at 870°C compared with IMI 318 alloy at 925°C. Although the pressure required for IMI 550 was greater, the lower forming temperature may reduce processing costs and subsequent heat treatment may lead to higher strength in the formed product compared with IMI 318 alloy. The m-value data for extruded material suggests more superplastic behaviour would be obtained at strain rates lower than those used in the present tests; ie 8×10^{-5} s^{-1}, which is about three times slower than the superplastic forming rates used for titanium alloy sheet. Further work is required to determine whether processing changes at the billet or extrusion stages can produce a more equiaxed microstructure with a finer grain size.

Conclusions

A conventionally extruded U-channel section in IMI 318 and IMI 550 alloys tested under conditions that produced superplasticity in thin sheet, exhibited enhanced plasticity but the deformation in the gauge length was non-uniform and in most positions in the extrusion, was anisotropic with flow stresses a factor 2 greater than for sheet. Changes in processing to produce a more equiaxed microstructure are required.

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17. Abstract

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